Lecture 2
Understand the sky we see from the Earth

Reading: Chapter 2 & S1

2. Discovering the Universe for Yourself
(what we see when we look up)

- Patterns in the Sky
- Motions in the Sky
  - The Circling Sky *day*
    - the rotation of the Earth about its axis
  - The Reason for Seasons *year*
    - the Earth's orbit around the Sun
  - Precession of the Earth's Axis
    - the wobbling of Earth's axis
  - The Moon, Our Constant Companion *month*
    - the Moon's orbit around the Earth
  - The Ancient Mystery of the Planets *week*
    - the various planets' orbits around the Sun

2.1 Patterns in the Sky

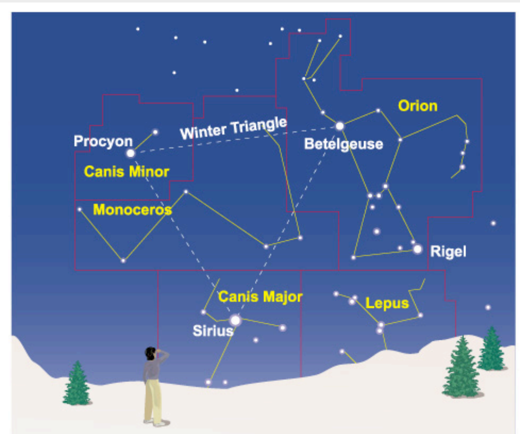
Our goals for learning:

- What is a **constellation**?
- What is the **celestial sphere**?
- Why do we see a band of light called the *Milky Way* in our sky?

A Constellation is…

… a *region* of the sky, within official borders set in 1928 by the IAU.

- Often recognizable by a pattern or grouping of stars.
- Some patterns, like the Winter Triangle, span several constellations.



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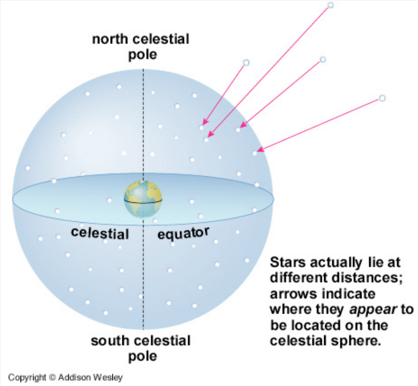
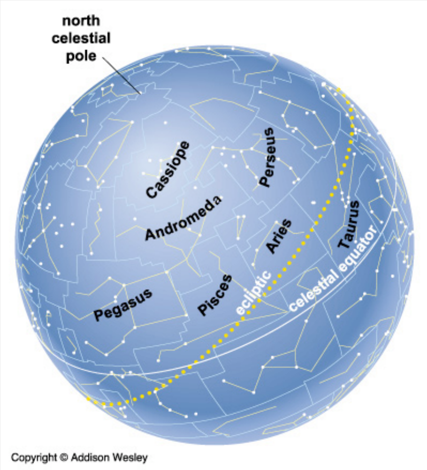
Constellations

- Most official constellation names come from antiquity. Some southern hemisphere constellations were named by European explorers in the 17th & 18th centuries.
- The patterns of stars have no physical significance! Stars that appear close together may lie at very different distances.

- Modern astronomers use them as landmarks.



The Celestial Sphere



- The sky above looks like a dome…a hemisphere..
- If we imagine the sky around the entire Earth, we have the **celestial sphere**.
- This a 2-dimensional representation of the sky
- Because it represents our view from Earth, we place the Earth in the center of this sphere.

The Celestial Sphere

North & South celestial poles

the points in the sky directly above the Earth's North and South poles

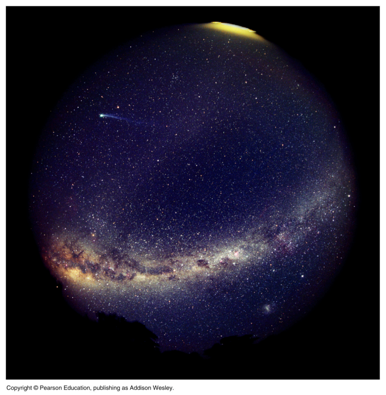
celestial equator

the extension of the Earth's equator onto the celestial sphere

ecliptic

the annual path of the Sun through the celestial sphere, which is a projection of ecliptic plane

The Milky Way

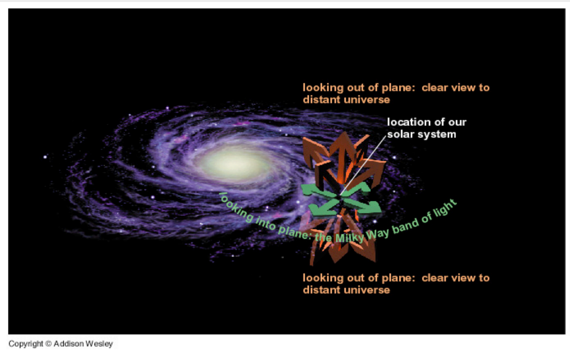


You've probably seen this band of light across the sky.

What are we actually seeing?

The Milky Way

- Our Galaxy is shaped like a disk.
- Our solar system is in that disk.
- When we look at the Milky Way in the sky, we are looking along that disk.



2.2 The Circling Sky

Our goals for learning:

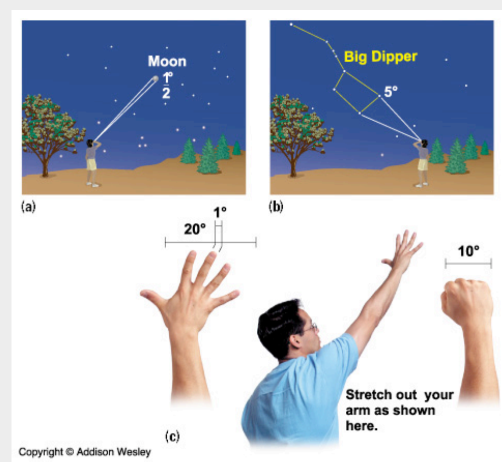
- Describe the basic features of the local sky.
- How does the sky vary with latitude?
- Why are some stars above the horizon at all times?
- How does the night sky change through the year?

Measuring the Sky

We measure the sky in *angles*, not distances.

- Full circle = 360°
- 1° = 60 arcmin
- 1 arcmin = 60 arcsec

Measuring Angles in the Sky



The Local Sky

zenith

the point directly above you

horizon

all points 90° from the zenith

altitude

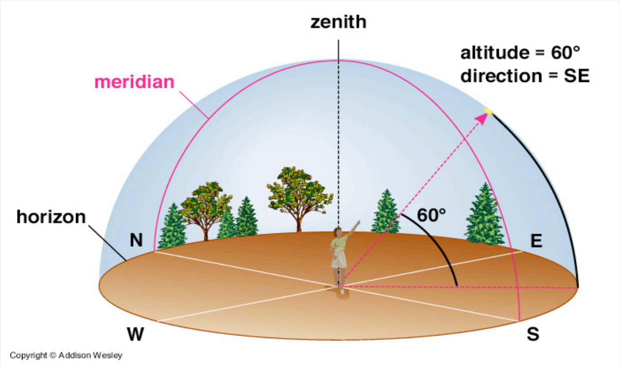
the angle above the horizon

meridian

due north horizon ⇒zenith ⇒due south horizon

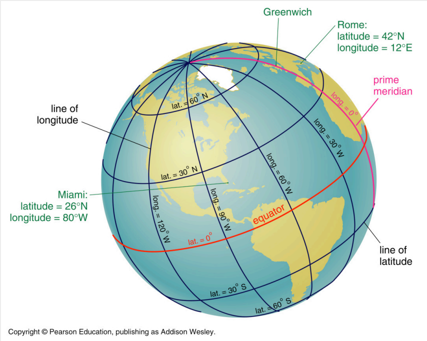
To pinpoint a spot in the local sky:

Specify altitude and direction along the horizon

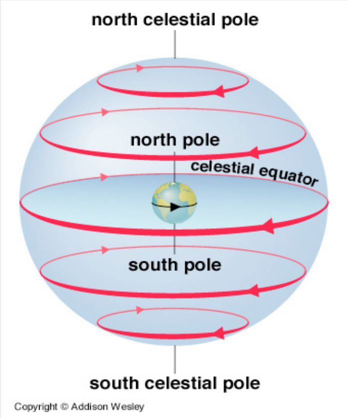


Review: Coordinates on the Earth

- Latitude: position north or south of equator
- Longitude: position east or west of prime meridian (runs through Greenwich, England)



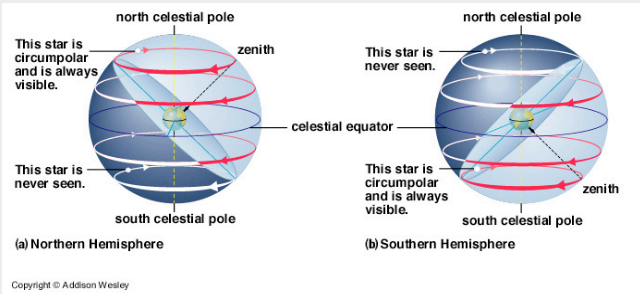
The Daily Motion



- As the Earth rotates, the sky appears to us to rotate in the opposite direction.
- The sky appears to rotate around the N (or S) celestial poles.
- If you are standing at the poles, nothing rises or sets.
- If you are standing at the equator, everything rises & sets 90° to the horizon.

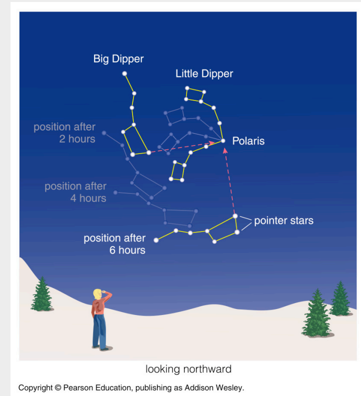
The Daily Motion

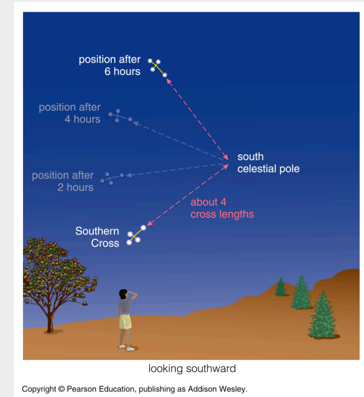
- The altitude of the celestial pole = [your latitude].
- All stars at an angle < [your latitude] away from:
  - your celestial pole never set. (**circumpolar**)
  - the other celestial pole are never seen by you.
- Other stars, (& Sun, Moon, planets) rise in East and set in West at an angle = [90° – your latitude].



The Daily Motion

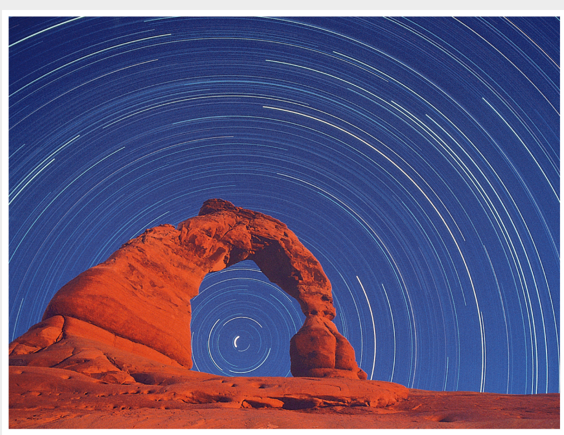
daily circles --- CCW looking north, CW looking south





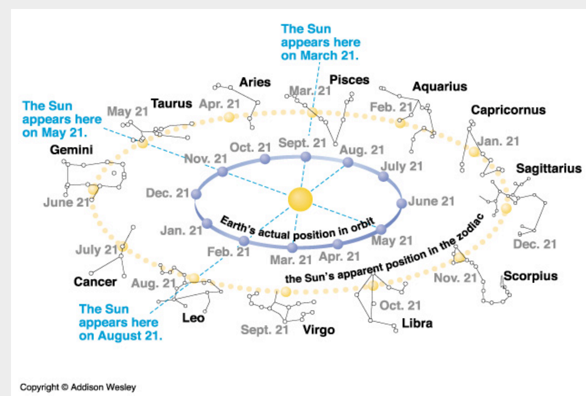
Time Exposure Photograph:

- Estimate time A: 6 hours, B: 12 hours, C: 24 hours
- Which direction did stars move? A: clockwise, B: counter-clockwise



Annual Motion

- As the Earth orbits the Sun, the Sun appears to move eastward with respect to the stars.
- The Sun circles the celestial sphere once every year.



2.3 Seasons

Our goals for learning:

- What is the cause of the seasons on Earth?
- Why are the warmest days typically a month after the beginning of summer?

Annual Motion

- The Earth's axis is tilted 23.5° from being perpendicular to the ecliptic plane.
- Therefore, the celestial equator is tilted 23.5° to the ecliptic.
- As seen from Earth, the Sun spends 6 months north of the celestial equator and 6 months south of the celestial equator.
- **Seasons** are caused by the Earth's axis tilt, *not* the distance from the Earth to the Sun!

Annual Motion

ecliptic

the apparent path of the Sun through the sky

equinox

where the ecliptic intersects the celestial equator

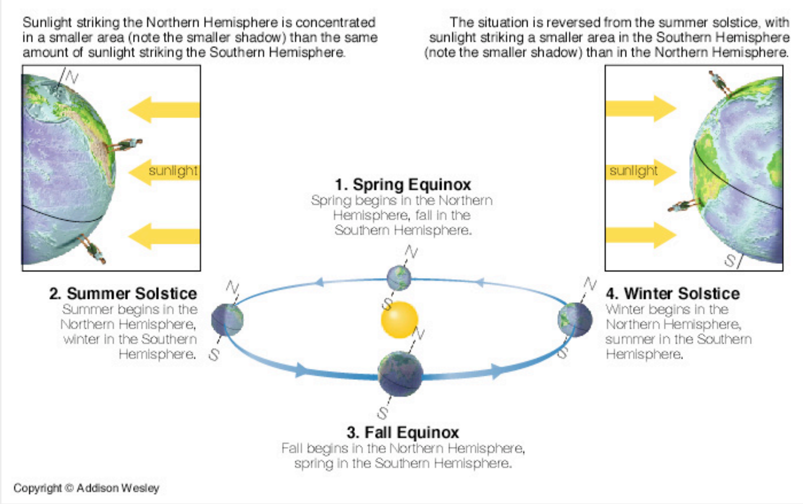
solstice

where the ecliptic is farthest from the celestial equator

zodiac

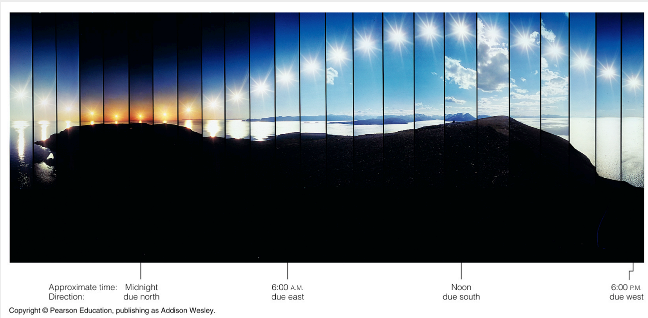
the constellations which lie along the ecliptic

The Cause of the Seasons



Seasonal changes are more extreme at high latitudes

Path of the Sun on the summer solstice at the Arctic Circle



When is summer?

- Although the solstice which occurs around June 21 is considered the first day of summer.
- It takes time for the more direct sunlight to heat up the land and water.
- Therefore, July & August are typically hotter than June.

2.4 Precession

Our goals for learning:

- What is the Earth's cycle of precession?

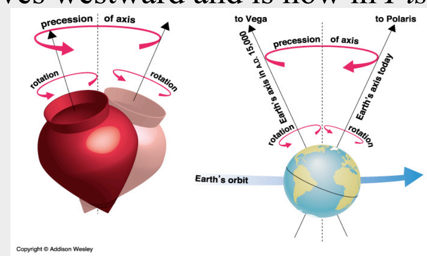
Precession of the Equinoxes

• The Earth's axis precesses (wobbles) like a top, once about every 26,000 years.

• Precession changes the positions in the sky of the celestial poles and the equinoxes.

⇒ *Polaris* won't always be the north star.

⇒ The spring equinox, seen by ancient Greeks in *Aries*, moves westward and is now in *Pisces*!



2.5 The Moon, Our Constant Companion

Our goals for learning:

- Why do we see phases of the Moon?
- What conditions are necessary for an eclipse?
- Why were eclipses difficult for ancient peoples to predict ?

Lunar Motion

Phases of the Moon's 29.5 day cycle

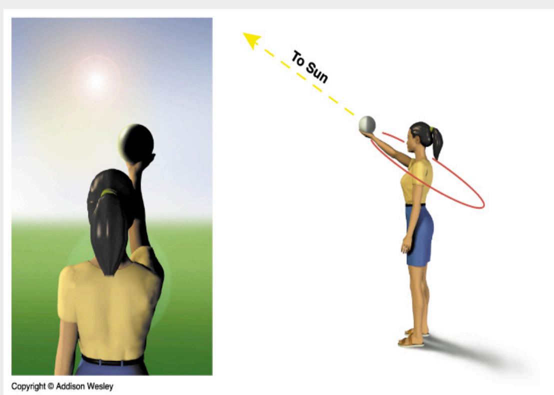
- new
- crescent
- first quarter
- gibbous
- full
- gibbous
- last quarter
- crescent

waxing

waning

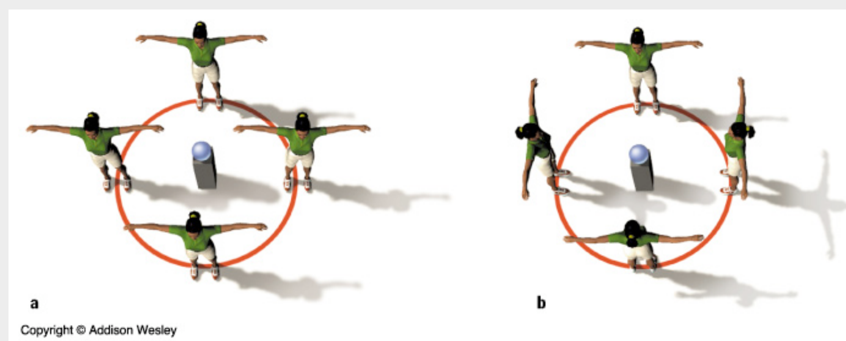
Why do we see phases?

- Half the Moon illuminated by Sun and half dark
- We see some combination of the bright and dark faces



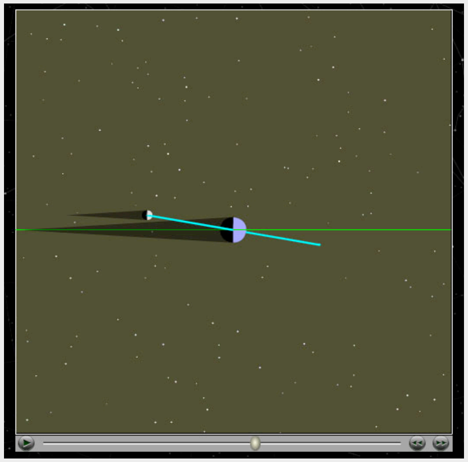
Why do we see the same face?

Rotation period = orbital period

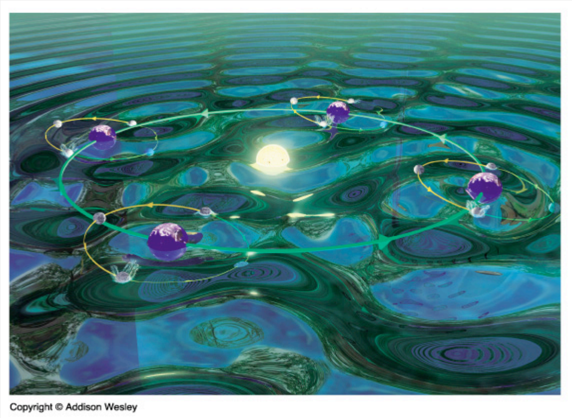


Eclipses

- The Earth & Moon cast shadows.
- When either passes through the other's shadow, we have an **eclipse**.
- Why don't we have an eclipse every full & new Moon?



- Moon's orbit tilted 5° to ecliptic plane
  – Crosses ecliptic plane only at the two **nodes**
  – Eclipse possible only when full/new occur near nodes



Eclipses

When the Moon's orbit intersects the ecliptic (node):

at new moon solar eclipse

you must be in Moon's shadow to see it

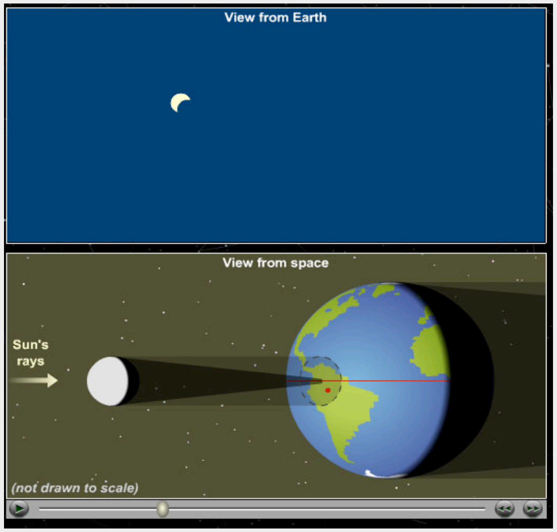
within umbra: total solar eclipse

within penumbra: partial solar eclipse

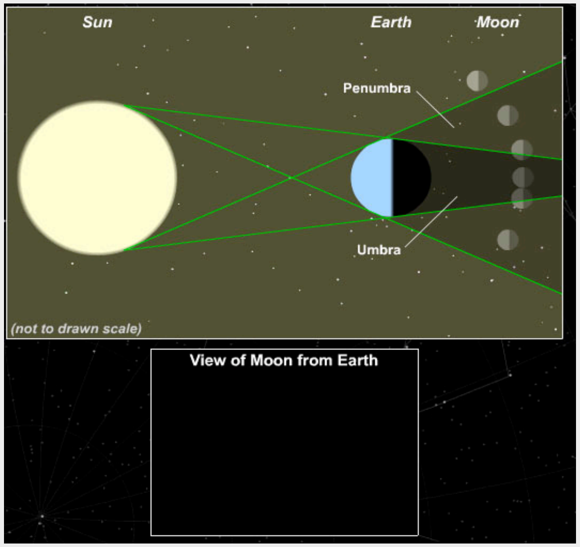
at full moon lunar eclipse

everyone on the nighttime side of Earth can see it

Solar Eclipse

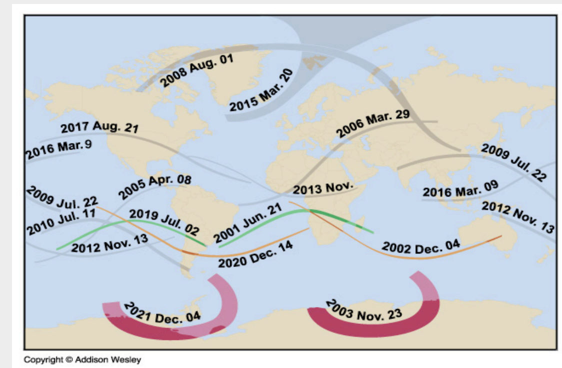


Lunar Eclipse



Eclipse Predictions

- Eclipses recur in the approx. 18 yr, 11 1/3 day saros cycle
- But even then, eclipse location and type (e.g., partial, total) may vary



2.6 The Ancient Mystery of the Planets

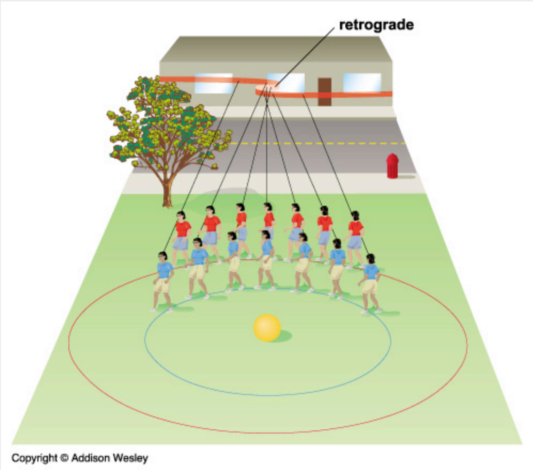
Our goals for learning:

- Why do planets sometimes seem to move backwards relative to the stars?
- Why did the ancient Greeks reject the idea that the Earth goes around the Sun, even though it offers a more natural explanation for planetary motion?

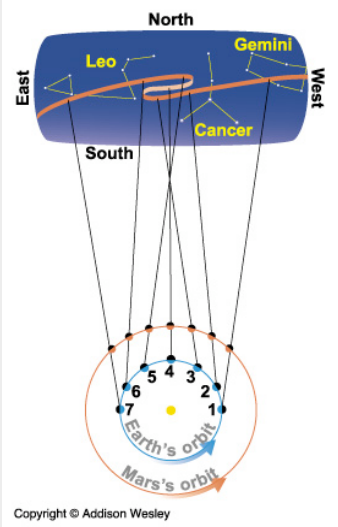
Planets Known in Ancient Times

- Mercury
  - difficult to see; always close to Sun in sky
- Venus
  - very bright when visible — morning or evening “star”
- Mars
  - noticeably red
- Jupiter
  - very bright
- Saturn
  - moderately bright

Apparent retrograde motion — try it yourself!



Retrograde Motion



- Like the Sun, planets usually appear to move eastward relative to the stars.
- But as we pass them by in our orbit, they move west relative to the stars for a few weeks or months.
- Noticeable over many nights; on a single night, a planet rises in east and sets in west…

Explaining Apparent Retrograde Motion

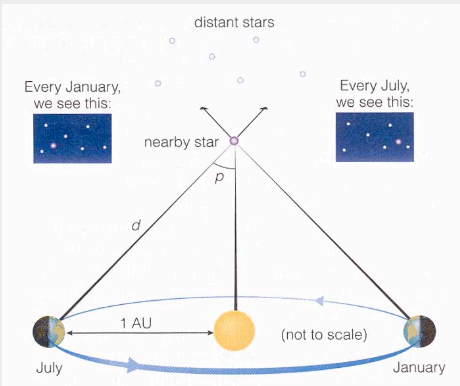
- Easy *for us* to explain: occurs when we "lap" another planet (or when Mercury or Venus lap us)
- But very difficult to explain if you think that Earth is the center of the universe!
- *In fact, ancients considered but rejected the correct explanation…*

Why did the ancient Greeks reject the notion that the Earth orbits the sun?

- It ran contrary to their senses.
- If the Earth rotated, then there should be a "great wind" as we moved through the air.
- Greeks knew that we should see stellar parallax if we orbited the Sun – but they could not detect it.

Parallax Angle

Apparent shift of a star's position due to the Earth's orbiting of the Sun



The nearest stars are much farther away than the Greeks thought.

So the parallax angles of the star are so small, that you need a telescope to observe them.

Possible reasons why stellar parallax was undetectable:

1. Stars are so far away that stellar parallax is too small for naked eye to notice
2. Earth does not orbit Sun; it is the center of the universe

Unfortunately, with notable exceptions like Aristarchus, the Greeks did not think the stars could be *that* far away, and therefore rejected the correct explanation (1)…

Thus setting the stage for the long, historical showdown between Earth-centered and Sun-centered systems.

What have we learned?

- What is a **constellation**?
  - A constellation is a region of the sky. The sky is divided into 88 official constellations.
- What is the **celestial sphere**?
  - An imaginary sphere surrounding the Earth upon which the stars, Sun, Moon, and planets appear to reside.
- Why do we see a band of light called the *Milky Way* in our sky?
  - It traces the Galactic plane as it appears from our location in the *Milky Way Galaxy*.

What have we learned?

- Describe the basic features of the local sky.
  - The horizon is the boundary between Earth and sky. The meridian traces a half circle from due south on your horizon, through the zenith (the point directly overhead), to due north on your horizon. Any point in the sky can be located by its altitude and direction.
- How does the sky vary with latitude?
  - As the celestial sphere appears to rotate around us each day, we see different portions of the paths of stars from different latitudes. The altitude of the celestial pole (north or south) is the same as your latitude (north or south).

What have we learned?

- Why are some stars above the horizon at all times?
  - All stars appear to make a daily circle. Circumpolar stars are those for which their entire daily circles are above the horizon, which depends on latitude.
- What is the cause of the seasons on Earth?
  - As the Earth orbits the sun, the tilt of the axis causes different portions of the Earth to receive more or less direct sunlight at different times of year. The two hemispheres have opposite seasons. The summer solstice is the time when the northern hemisphere gets its most direct sunlight; the winter solstice is the time when the southern hemisphere gets its most direct sunlight. The two hemispheres get equally direct sunlight on the spring and fall equinoxes.

What have we learned?

- Why are the warmest days typically a month after the beginning of summer?
  - The summer solstice is usually considered the first day of summer, but the warmest days come later because it takes time for the more direct sunlight to heat up the ground and oceans from the winter cold.
- How does the night sky change through the year?
  - The visible constellations at a particular time of night depend on where the Earth is located in its orbit around the Sun.
- What is the Earth's cycle of precession?
  - A roughly 26,000 year cycle over which the earth's axis traces a cone as it gradually points to different places in space.

What have we learned?

- Why do we see phases of the Moon?
  - At any time, half the Moon is illuminated by the Sun and half is in darkness. The face of the Moon that we see is some combination of these two portions, determined by the relative locations of the Sun, Earth, and Moon.
- What conditions are necessary for an eclipse?
  - An eclipse can occur only when the nodes of the Moon's orbit are nearly aligned with the Earth and the Sun. When this condition is met, we can get a solar eclipse at new moon and a lunar eclipse at full moon.

What have we learned?

- Why were eclipses difficult for ancient peoples to predict ?
  - There are 3 types of solar eclipse and 3 types of lunar eclipse. Although the pattern of eclipses repeats with the approximately 18-year saros cycle, they do not necessarily repeat with the same type of eclipse and are not necessarily visible from the same places on Earth.
- Why do planets sometimes seem to move backwards relative to the stars?
  - Apparent retrograde motion occurs over a period of a few weeks to a few months as the earth passes by another planet in its orbit.

What have we learned?

- Why did the ancient Greeks reject the idea that the Earth goes around the Sun, even though it offers a more natural explanation for planetary motion?
  - A major reason was their inability to detect stellar parallax --- the slight shifting of nearby stars against the background of more distant stars that occurs as the Earth orbits the Sun. To most Greeks, it seemed unlikely that the stars could be so far away as to make parallax undetectable to the naked eye, even though that is in fact the case. They instead explained the lack of detectable parallax by imagining the Earth to be stationary at the center of the Universe.